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Continuous Wavelet Transforms of Spectral Decomposition and Petrophysical Analyses For Sand Reservoir Characterization Of X Gas Field, Eastern Indonesia

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Abstract. Hydrocarbon exploration in Eastern Indonesia is still a challenging area. This region provides a great challenge for future significant discoveries. This potential was evaluated in order to explore the target for geoscientists and petroleum engineers. Various studies have demonstrated the usefulness of spectral decomposition and its associated frequency attributes in seismic interpretation and hydrocarbon exploration. In this work, we used Continuous Wavelet Transform (CWT) to to detect frequency shadows caused by hydrocarbons for reservoir characterization.Wavelet transform is a useful and applicable technique to reveal frequency contents of various signals in different branches of science and especially in petroleum studies. We also applied petrophysical analysis to evaluate the reservoir quality, it applied to get the petrophysical parameters consist of porosity, shale volume, resistivity, and water saturation. The evaluated petrophysical parameter indicated that there were good porosity ranges between (5-25%), clay volume (11-14%), and water saturation (2-30%). Lithology of reservoir is sand. The evaluated petrophysical parameters indicated reservoir in this gas field has good quality of reservoir.It had been observed that continuous wavelet transform, utilizing Morlet wavelet, displays low-frequency shadows under the reservoir on iso-frequency vertical sections to identify reservoirs containing gas.The presence of low-frequency shadows under the reservoir can be an indicator of the presence of hydrocarbons in the target reservoir.

Keywords: continuous wavelet transform (CWT), petrophysical analysis, low-frequency shadows

1. Introduction

Oil and gas reservoirs can cause anomalies in the energy and frequency of seismic signals. We can take advantage of these anomalies for hydrocarbon detection. Strong amplitude anomalies at specific frequencies can be easily found by using spectral decomposition [1]. As a spectral decomposition method, the Continuous Wavelet Transforms (CWT) method, combined with petrophysical analysis is proposed for hydrocarbon detection in tight sand reservoirs.

CWT method provides a different approach to time–frequency analysis. It utilizing a complex Morlet analyzing wavelet has a close connection to the Fourier transform and is a powerful analysis tool for decomposing broadband wave field data. A wide range of seismic wavelet applications have been reported over the last three decades [5].

Over the past two decades, wavelet transform has been applied in many branches of science and engineering. *Castagna et al.* [2] showed compelling examples that gas reservoirs could be identified by low-frequency shadows in a time-frequency spectrum. Based on that experience, we conduct an investigation that reveals the existence of the low-frequency shadow associated with a gas reservoir. In this research, various models were analyzed to observe spectral decomposition response of fluids and selected frequencies were applied for the prediction of hydrocarbons.

The main objective of this study is to apply Continuous Wavelet Transforms (CWT) of spectral decomposition as seismic attributes combined with petrophysical analysis (porosity, resistivity, volume of shale and water saturation) to enhance reservoir characterization of X gas field located in Eastern Indonesia. By applying these techniques it is possible to better understand the characteristics of reservoir, and to define reservoir elements that cannot be seen in conventional seismic data.

2. Methodology

Petrophysics analysis and Continuous Wavelet Transforms (CWT) of spectral decomposition were the two main methods that were used to identify gas sands within the study area.

2.1. Petrophysics Analysis
The well log data of four wells drilled in the study area were used for rock physics analysis to determine rock physics properties that best distinguish lithology and fluid types within the reservoir zone. Logging data from wells ZR-1, ZR-2, ZR-3 and ZR-4 used in this study comprises of neutron and density logs, Laterolog Deep log (LLD), and Gamma Ray log (GR). These logs are used to evaluate and analyze the petrophysical properties such as porosity(Φ), water saturation(Sw), and volume of shale (Vsh).

The gamma ray and resistivity logs were used for the identification of lithologies and hydrocarbon-bearing reservoirs. The reservoir fluids were characterized using resistivity log and water saturation value. The clay content was calculated from gamma ray logs [7]. The corrected porosity was estimated using density log, after applying various corrections [4]. The water saturation was computed using the Indonesian equation, in which a factor and cementation exponent were derived from core analysis (a= 1, m=1.2, n=2) [3].

2.2. Continuous Wavelet Transforms (CWT) Analysis
In this study, we have applied CWT on full stack high resolution 3D seismic data to check the frequency response using the time-frequency analysis of spectral decomposition of CWT for analysis of gas reservoir sands. The Morlet wavelet is used as mother wavelet in this study.

Before applying wavelet decomposition analysis techniques to the entire 3D seismic data, a single seismic trace at well locations should be analyzed first to determine the tunning frequency. The value of tunning frequency will be used as the input frequency of the wavelet transform for the entire 3D seismic data. Figure 1 displays the seismic section of NW-SE direction crossing ZR-1, ZR-2, ZR-3, and ZR-4. Two reflection events were picked on the seismic sections. The top reservoir marked with yellow colour, is the primary target. The base reservoir marked with green colour.

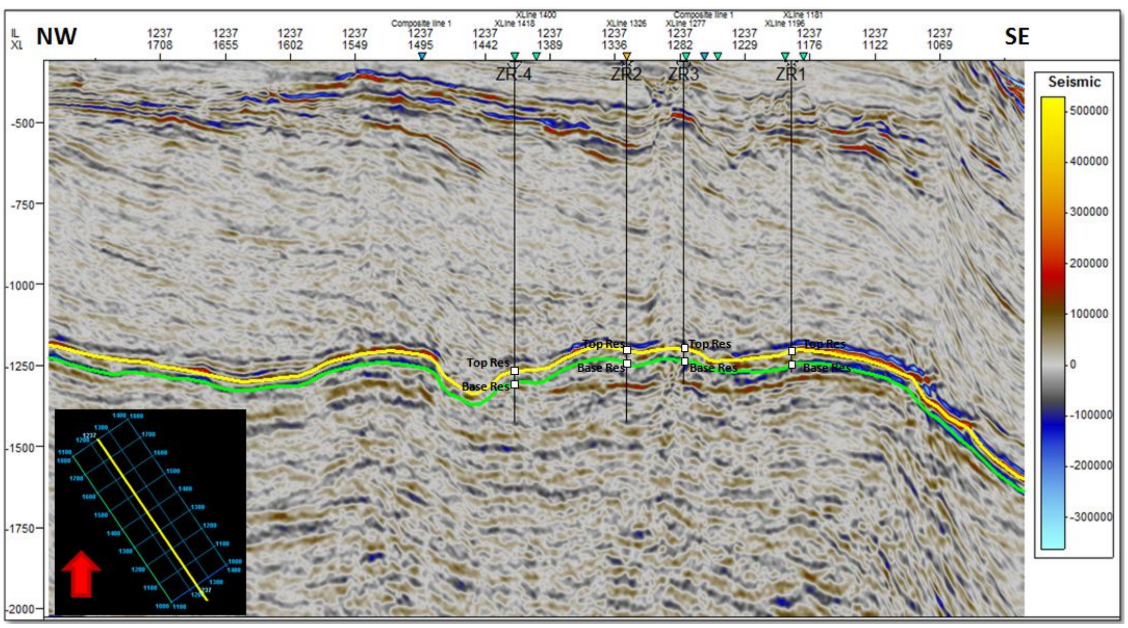

Figure 1. Seismic section of NW-SE direction crossing wells ZR-1, ZR2, ZR-3, and ZR-4.

Section of the time-frequency analysis which is applied to single seismic trace around observed well is shown in Figure 2. Based on the information provided in the petrophysical and log data, there is one major hydrocarbon zones. As a result, there should be also one high energy signatures showing on the spectrogram (frequency 12 Hz) (Figure 2(b)). The frequency that could catch the high energy zone is around 12 Hz. Furthermore, frequency 12 Hz was selected as the tunning frequency for low frequency analysis. Then, a cross section spectrogram will be constructed.

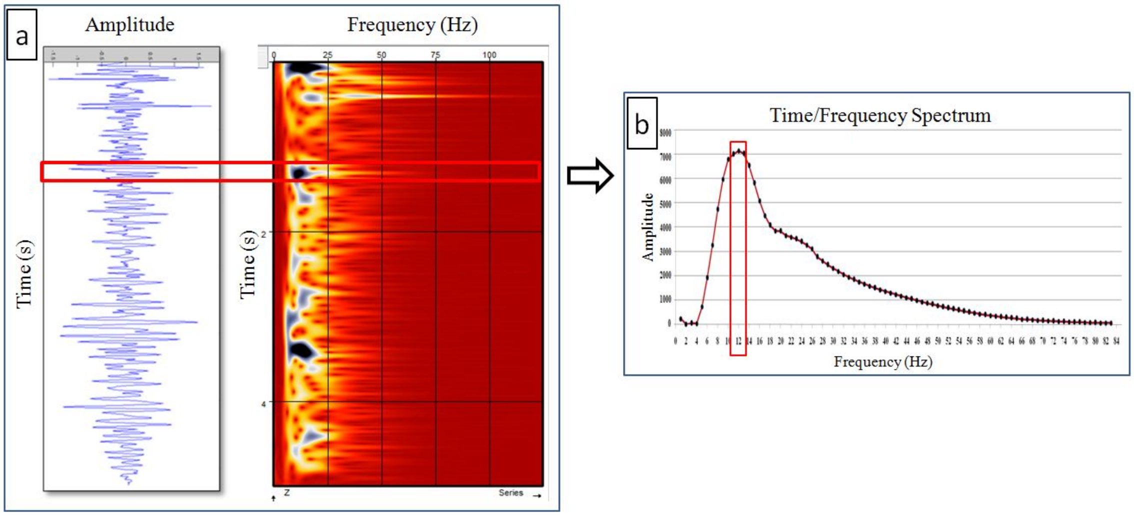

Figure 2.The process of tunning frequency determination (a) Section of time-frequency analysis (spectrogram) which applied to single seismic trace around well ZR-1. Area in the red box is position of gas reservoir (b) Time/Freqency spectrum of gas reservoir layer. The red box is high amplitude of signal to determine the tunning frequency (12 Hz).

3. Results and Discussion

This section is divided into two parts, petrophysics analysis and Continuous Wavelet Transform (CWT) analysis. The results of both of these techniques are discussed separately.

3.1. Petrophysics Analysis

High resisitivity log reading and separation of the neutron-density log with the neutron log deflecting to the right and density log to the left indicated the present of hydrocarbon. The results of the interpreted well logs revealed one hydrocarbon-bearing sandstone reservoir in each of the wells (Well ZR-1, ZR-2, and ZR-3). While, no presence of hydrocarbon in Well ZR-4, because the parameters of log data not supported the presence of hydrocarbon in this well. The gamma ray log shows the lithology of reservoir is sandstone as a low gamma ray reading unit.The low GR, high resistivity, low neutron and low density log responses indicated that hydrocarbon type was gas. Figure 3 shows log data of well ZR-3 with gas saturated sandstone (highlighted zone) as example of log data analysis of sandstone reservoir.

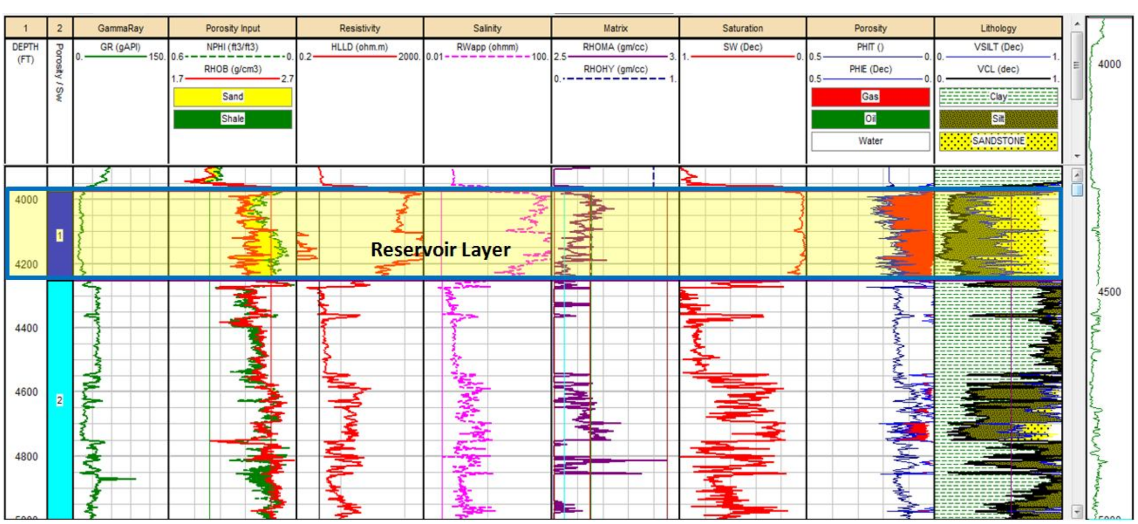

Figure 3. Petrophysics analysis well ZR-3 with gas saturated sandstone (highlighted zone) as example of log data analysis of sandstone reservoir.

The Summary of petrophysics analysis from 4 wells is shown in Table 1. The porosity values range from 5 to 25%, it shows that the reservoir has good quality reservoir sands. The water saturation values range is from 2 to 30%. The clay volume of the reservoir is low, varying between 11 and 14 %. It is indicating of low effect of clay in the reservoir.

Table 1. The summary of petrophysics analysis from wellsZR-1, ZR-2, ZR-3, and ZR-4

No	Well	Top (ft)	Bottom (ft)	Thickness (ft)	Vsh %	Sw (%)	Porosity (%)
1	ZR-1	4188	4425	237	12	2-18	5-20
2	ZR-2	4225	4540	315	11	10-30	5-15
3	ZR-3	3978	4258	280	14	2-10	10-25
4	ZR-4	No presence of hydrocarbon					

3.2. Continuous Wavelet Transforms (CWT) Analysis

A 12 Hz seismic section obtained using CWT processing of the seismic data shown in Figure 4. A high-energy low-frequency shadow zone can be observed under the Top Reservoir. The gas-saturated target sand is nicely highlighted at this frequency. We believe this to be a low-frequency shadow. The low frequency energy at 12 Hz is seen at the target sand horizon near the Well ZR-1, ZR-2 and ZR-3 location, but does not appear near the Well ZR-4 (the left part of figure 4 (b)), it caused by there are no presence of hidrocarbon in this area. This analysis shows that the low frequency sections from CWT has been able to detect low frequency anomalies caused by hydrocarbons [6].

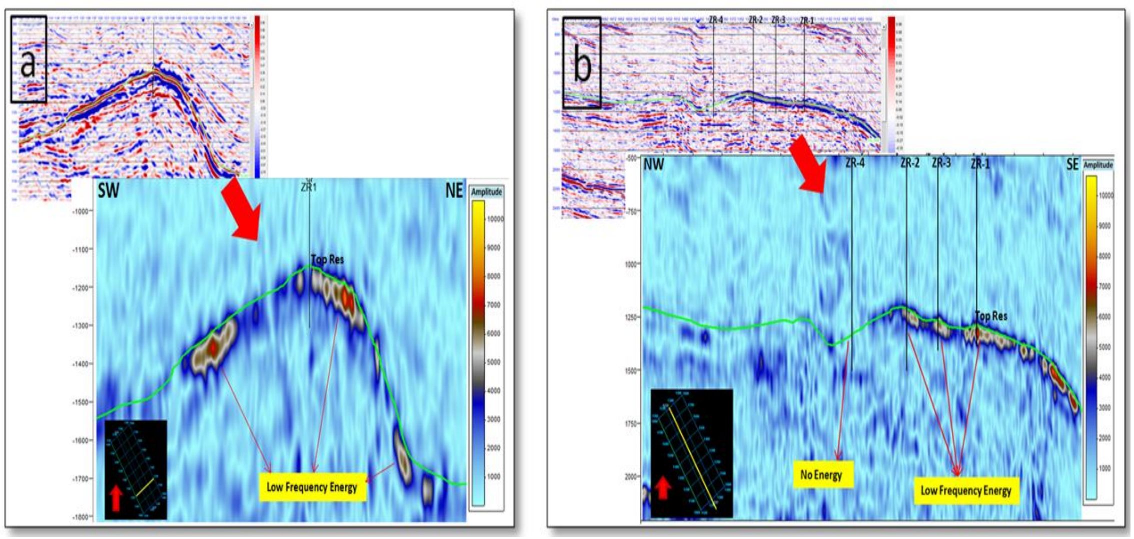

Figure 4. (a) Cross section spectrograms of 12 Hz (b) Inline cross section spectrogram of 12 Hz. Low frequency energy anomalies shown in red are at the hydrocarbon zones.

Viewing frequency-dependent effects in map view is also very revealing. Figure 5 shows frequency-dependent horizon slice at the top of the reservoir. Based on figure 5, high amplitudes are found in the southeast of the research area (around wells ZR-1, ZR-2 and ZR-3). While high amplitudes did not find high amplitudo in the northwest of the research area (around wells ZR-4). This indicates that the gas distribution is in the southeast area of the study area.

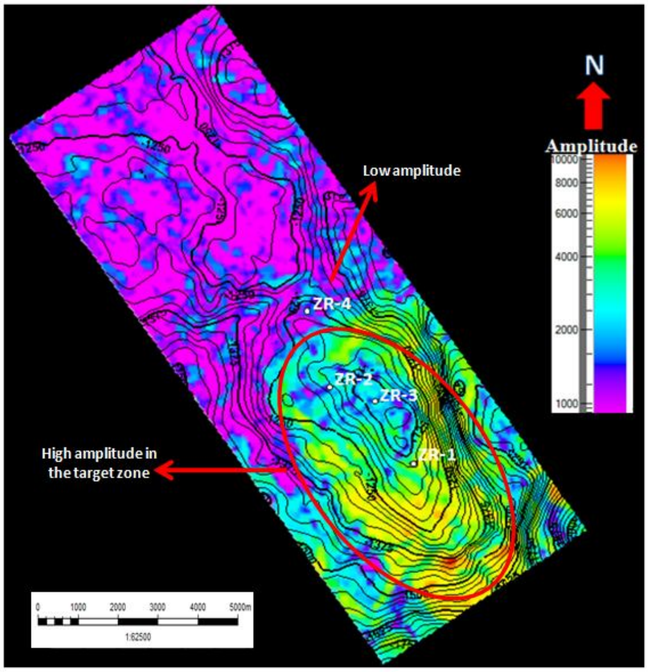

Figure 5. 12 Hz common frequency horizon slice on 50-ms window immediately below the reservoir.

4. Conclusions

Based on our study, Continuous Wavelet Transform (CWT) is an effective method with extensive uses in the petroleum engineering industry. As a result of these wide applications, the hydrocarbon are visible in the horizontal section rather than in CWT vertical results, and some important oil reservoirs have been mapped in this area of study. On the other hand, CWT is used for showing the presence of hydrocarbon by using the so-called effect of low frequency shadows under gas reservoirs. One can clearly see that the hydrocarbons are responsible for the high amplitudes at and around 12 Hz. The evaluated petrophysical parameter (porosity, water saturation, and volume of shale) indicated reservoir in this gas field has good quality of reservoir.

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